New distant companions to known nearby stars: I. GJ 4047B, GJ 718B, GJ 747.2C, GJ 4100B, and GJ 4153B.[1]

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ABSTRACT

In an ongoing survey for high proper motion stars at low galactic latitudes ($-25° < b < 25°$), we have identified 5 previously uncatalogued common proper motion companions to stars listed in the *Preliminary Version of the Third Catalogue of Nearby Stars* (GJ stars). For each system, the relative proper motion between the components is less than 5% of the common proper motion of the pair. Spectra of the pairs have been obtained at the Lick 3-m Shane Telescope, confirming that the systems are indeed wide separation binaries. The systems are classified as follows: GJ 4047AB = K5 V + M5 V, GJ 718AB = K5 V + M4.5 V, GJ 747.2ABC = (K7 V + K7 V) + M4 Ve, GJ 4100AB = M1 V + M4.5 Ve, and GJ 4153AB = M0.5 V + M3.5 V. The total area surveyed contains 346 Gliese stars, which suggests that $\approx$ 1.5% of the stars listed in the *Preliminary Version of the Third Catalogue of Nearby Stars* have unrecognized proper motion companions. We predict that ≈15-50 more new distant companions to GJ stars will be discovered in the Digitized Sky Survey.

Subject headings: Stars: low-mass, brown dwarfs — Binaries: visual — Stars: fundamental parameters

1. Introduction

The current census of stars in the solar neighborhood is believed to be significantly incomplete, even within only 10pc of the sun (Henry *et al.* 1997, Delfosse *et al.* 2000). The ongoing search for nearby stars is a challenge because the vast majority of stellar objects in the Galaxy consist of intrinsically faint M dwarf stars, whose absolute visual magnitudes are in the $10 < M_V < 20$ range. Not only are there several stellar systems waiting to be

discovered, but it is very likely that a significant number of known nearby systems are yet to be recognized as multiple stars. A census of the stars in the immediate vicinity ($d < 5$pc) of the sun reveals that more than half of the stellar bodies are members of double and triple stellar systems (van de Kamp 1971). On the other hand, the *Third Catalog of Nearby Stars* by Gliese & Jahreiss 1991 (hereafter GJ), lists only 1031 bodies in multiple systems out of a total of 3803 stars.

Multiplicity among nearby M dwarf stars has been discussed and estimated by Fischer & Marcy (1992). Methods for the identification of companions depend on the separation (semi-major axis a) between the components. For stars in the solar neighborhood, very close companions $a < 1$ AU can generally be identified as spectroscopic binaries. Systems with intermediate separations (1 AU$< a <$25 AU) are best found with high-resolution imaging techniques. Nearby wide binaries, on the other hand, are well resolved on the sky, even on old photographic plates, and the challenge is to distinguish them from background stars. The main method to identify the components of nearby wide binaries is through their common proper motion.

While close and intermediate separation binaries require intensive observational efforts, wide binaries can be identified using available all-sky surveys, provided they are sensitive enough to detect the companion as a high proper motion object. A list of wide binaries has been compiled by Poveda *et al.* 1994 (hereafter PHACL). Expanding on the GJ catalog, they searched for unaccounted common proper motion companions to GJ stars within 22.5pc of the sun by correlating the GJ stars with entries in the *catalog of Double Stars with Common Proper Motion* (LDS catalog, Luyten 1987) and in the *New Luyten Catalogue of stars with proper motions larger than two tenths of an arcsecond* (NLTT catalog, Luyten 1980). They found 18 more systems overlooked by GJ. The compilation given in PHACL includes 305 wide binaries, 26 triples, and 3 quadruples, all systems with a semi-major axis

$a > 25$AU, i.e. with an angular separation exceeding $1''$. The fact that PHACL reports 18 companions not listed in GJ strongly suggest that there are many more companions to be found, because *both the NLTT and LDS catalogs are themselves significantly incomplete.*

Two recent studies have provided a striking demonstration of the effect of incompleteness of high proper motion star catalogs on the current census of wide binary systems. McCarthy, Zuckerman, & Becklin (2001) have discovered one previously unrecognized, faint common proper motion companion to the star G144-016 (GJ 4153). They serendipitously found the faint common proper motion companion (located $1'$ from G144-016) by comparing their finding charts drawn from first and second epoch Digitized Sky Survey (DSS) images. In another survey for substellar companions to nearby stars, Kirkpatrick *et al.* (2001) report the discovery of three faint companions to known nearby stars based on their IR colors as obtained from the 2MASS survey. One of the secondaries (G216-7 B) was also identified as a previously unrecognized faint proper motion companion, visible on the first and second epoch DSS images. These two studies suggest that a systematic search for proper motion companions on Palomar sky survey plates should reveal several more distant companions to known nearby stars.

We have initiated a systematic, automated search for high proper motion stars using the DSS (Lépine *et al.* 2002, in preparation). We are particularly interested in the fields at low galactic latitudes, where the NLTT catalog is clearly deficient (≈ 1 star per square degree at $-10° < b < +10°$, compared with ≈ 3 stars per square degree at $b > +80°$). We are using the SUPERBLINK software, developed by SL, which works as an automated blink comparator. We have so far discovered several thousand stars that are well within the limits of the NLTT catalog ($\mu > 0.18''$ yr^{-1}, $R < 19$) but have been missed by Luyten for a variety of reasons. We suspect that most of the stars have been missed because of the obvious difficulties involved when visually searching for moving objects in very crowded fields with

the blink comparator. A computer-based search proves to be much more powerful and efficient.

By comparing the list of new high proper motion stars found by our software with objects listed in the GJ catalog, we have discovered 5 common proper motion companions to GJ objects previously listed as single stars. In this paper, we present spectroscopic observations of those newly identified wide multiples. One of the companions, GJ 4153B, has already been discovered serendipitously by McCarthy, Zuckermann, & Becklin (2001). The other four common proper motion companions are being cited here for the first time. This paper presents spectroscopic follow-up of the five common proper motion pairs, which confirms that they are physically related, low-mass, M dwarf companions to the known GJ stars. We discuss the potential for new discoveries in the conclusion.

2. Identification Method

We are conducting a systematic, automated survey for high proper motion stars at low galactic latitudes using the SUPERBLINK software. Using a differential technique, SUPERBLINK automatically searches for and identifies variable and moving objects on sub-images of the first and second Palomar Sky survey retrieved from the DSS. The code identifies stars with proper motions $\mu \gtrsim 100$ mas yr^{-1} and measures their proper motions with an accuracy of ≈ 5 mas yr^{-1}. Each candidate high proper motion star is verified visually by blinking $2' \times 2'$ sub-images centered on the candidate; bogus detections from e.g. plate artifacts, dust specks, scanning errors, are thus eliminated. As a preliminary study, we have investigated an area of the sky delimited by $DEC > -2.5°$, $16h < RA < 22h$, and covering the low galactic latitudes region ($-25° < b < +25°$). Within these limits, our SUPERBLINK software has identified 18,953 stars with $\mu > 0.10''$ yr^{-1}, all of which have been confirmed by visually blinking the candidates' images. We have found a total of 4,287

stars with $\mu > 0.18''$ yr^{-1}, of which 2,107 are "new" stars not listed in the NLTT catalog but within its limits.

The area under study covers an area ≈ 4500 square degrees, and contains a total of 346 stars listed in the GJ catalog. We used the VizieR web interface at the *Centre de Données Astronomiques de Strasbourg* to correlate all of our stars with $\mu > 0.10''$ yr^{-1} with the GJ catalog of nearby stars. We looked for any object in our catalog located within $1.5'$ of a known nearby star, and verified whether the object had a proper motion similar in magnitude and orientation as the proper motion of the GJ star. We identified 5 stars meeting this criterion which were *not* already listed in the GJ catalog. Finder charts for the five pairs are shown in Figures 1-5. In each case we show the POSS-I image to the left (epoch$\approx$1950) and the POSS-II image to the right (epoch$\approx$1990).

One of the companions we found is GJ 4153B, first identified by McCarthy, Zuckermann, & Becklin (2001). We verified with the SIMBAD Astronomical Database and confirmed that the other 4 companions had never been cited in the literature before. All 5 stars were selected for follow-up spectroscopic observations, since McCarthy, Zuckermann, & Becklin (2001) did not publish a spectrum for GJ 4153B.

3. Spectroscopic Observations

Spectra of the five systems were obtained at the Lick Observatory with the KAST spectrograph mounted on the 3.0-m Shane Telescope, under photometric conditions on the night of July 23-24, 2001 (heliocentric Julian date 2,452,114). Longslit spectra were obtained with the stars centered on a $2.5''$ wide slit. The instrument rotator was used, and set for each object such that the slit was oriented at the parallactic angle in order to avoid slit losses due to atmospheric differential refraction (Filippenko 1982). Four spectroscopic

standards were observed during the run (Feige 110, PG 1545+035, PG1708+602, and Wolf 1346, see Massey & Gronwall 1990), and were used for calibration and as templates for the removal of telluric lines. In order to correct for the fringing on the CCD, which is significant on the red channel of the KAST spectrograph redward of 7500 Å, we obtained separate dome flats for each target at the same telescope orientations (azimuth-altitude) as the observations.

Reduction was carried out with IRAF, using the standard procedure for the reduction of longslit spectra (DOSLIT), including calibration and removal of the telluric lines. The resulting spectra are presented for each system in Figures 1-5, with both the primary and the secondary plotted on the same graph *on a logarithmic scale* to emphasize the difference in the monochromatic fluxes.

Our spectral classification is based on the strength of the TiO5, CaH2, and CaH3 spectral indices as defined and calibrated in Reid *et al.* (1995) and Gizis (1997). We have also used the CaH1/TiO5, CaH2/TiO5, and CaH3/TiO5 ratios (see Gizis 1997) to determine whether the stars are dwarfs or subdwarfs; the M stars are all clearly dwarfs under this system. The values of the TiO5, CaH1, CaH2, CaH3 indices are listed in Table 2 along with the estimated spectral types. The estimated spectral types are the average spectral types obtained from the Reid *et al.* (1995) TiO5 index calibration and the Gizis (1997) TiO5, CaH2, and CaH3 indices calibrations; the accuracy is half a spectral type.

4. Discussion

4.1. *GJ 4047AB*

GJ 4047 is the bright high proper motion star known as Ross 706. It is the HIPPARCOS star HIPP-89656, a $V = 9.710$ mag star with a proper motion $\mu = 345.8$ mas yr^{-1} and

parallax $px = 31.65 \pm 1.47$mas, which places it at a distance d$\approx$ 32pc. The star was classified as K4 by G. P. Kuiper (published posthumously by Bidelman 1985), and listed as K3 in the catalog of *Nearby Stars, Preliminary 3rd Version* (Gliese & Jahreiss 1991). In 1991, the most accurate parallax measurements placed the star just within the 25pc limit of the Gliese & Jahreiss catalog, although the star is now believed to be outside the 25pc range.

We have found an $r = 16.0$ star $40.8''$ to the southwest of GJ 4047 which has a proper motion extremely similar to GJ 4047 (Figure 1). On the POSS-I plate, the object is blended with a background star. Our Lick spectrum shows the star to be an M5 V dwarf, which is largely consistent with the star being at 32pc. We conclude that the star is a distant companion on a long period orbit, with a current projected separation r$\approx$1260 AU. We hereby adopt the name GJ 4047A for the primary, and GJ 4047B for the low-mass secondary.

We do measure a small relative proper motion of $\approx$ 15mas yr^{-1} between the two stars. The mean error on our proper motion measurements is $\approx$ 5 mas yr^{-1}. The measured relative proper motion is thus significant at the 3σ level. Assuming a total system mass $\approx 0.8 M_{\odot}$, the orbital period will be $\approx 5 \times 10^4$ yr, which translates into a possible relative proper motion $\approx$ 5 mas yr^{-1} at 32pc for this system. Orbital motion is thus a reasonable explanation for the observed relative proper motion.

EDITOR: PLACE FIGURE 1 HERE.

4.2. *GJ 718AB*

GJ 718 is the bright variable star V774 Her, a known nearby flare star. It is the HIPPARCOS star HIPP-90959, a V=8.90 star with proper motion $\mu = 505.2$ mas yr^{-1}, and parallax $\pi = 42.67 \pm 1.26$ mas which places it at a distance d≈23pc. The star was classified K4 V by Cowley, Hiltner & Witt (1967), and K5 V by Stephenson (1986).

We have found an $r = 14.9$ star 51.6″ to the northwest which shares the same proper motion as GJ 718 (Figure 2). The star is blended with a background source in the POSS-I image. Our Lick spectrum reveals a spectral type M4.5 V, consistent with the star being a nearby low-mass dwarf. The star must be a companion on a long period orbit, with a current projected separation ≈1190AU. We hereby adopt the name GJ 718A for the primary, and GJ 718B for the low-mass secondary. We do not find any significant relative proper motion between the two stars.

EDITOR: PLACE FIGURE 2 HERE.

4.3. *GJ 747.2(AB)C*

The star GJ 747.2 is the double star COU 1462, resolved into two components of equal magnitude by Couteau (1977). Speckle interferometry measurements carried out in 1994 show two stars with a separation $\rho = 0.142''$ (Hartkopf *et al.* 2000). GJ 747.2 was observed as a single star by HIPPARCOS, and is now listed as a V=9.42 star with parallax $\pi = 34.37 \pm 1.30$ mas (catalog number HIP 94056), which places it at a distance of ≈ 29 parsecs. At this distance, the projected separation between the close components is only ~ 4 AU, and the orbital motion should be observed on timescales of years to decades. Observations carried out since the 1960s indeed show significant variations in

both separation and position angle (Couteau 1995), which can be attributed to the orbital motion, although the orbit has not been modeled yet. We will refer to the two components as GJ 747.2A and GJ 747.2B, though we refrain from specifically assigning those names to one star or the other at this point. This is meant only to identify the third member of the system as GJ 747.2C.

The star we now name GJ 747.2C is an $r = 13.6$ star lying $44.5''$ to the northeast of GJ 747.2AB, and having virtually the same proper motion as the close pair (Figure 3). Our Lick spectra show the star to be of spectral type M4 Ve, with the H_α line clearly in emission. Assuming a distance of 29pc, the tertiary has a projected separation of r≈1290 AU. We measure a relative proper motion between AB and C of ≈ 10 mas yr^{-1}, which is only significant at the 2σ level but could be related to the orbital motion of the tertiary. This system is listed as two point sources in the *2MASS Point Source Catalogue, 2MASS 2000 Second Incremental Release*. Components A and B have a combined infrared magnitude K_s=6.32, while component C has K_s=9.59.

EDITOR: PLACE FIGURE 3 HERE.

4.4. *GJ 4100AB*

This low galactic latitude (b=-3.57°) star was found in the Lowell proper motion survey (Giclas, Slaughter & Burnahm 1959). While it has no measured trigonometric parallax, its color and spectral type makes it a good candidate solar neighborhood star; it was included in the *Preliminary Version of the third catalogue of nearby stars* (Gliese & Jahreiss 1991). Its estimated distance is 15pc$\lesssim d \lesssim$45pc. This V$\simeq$12th magnitude star was not in the HIPPARCOS input catalog.

In the very crowded field around GJ 4100, we have found an $r = 16.6$th magnitude star 13.4″ to the northwest of GJ 4100 (Figure 4). The star is moving in the same direction and at the same proper motion rate as GJ 4100. Our Lick spectrum shows the star to be a low-mass M dwarf of spectral type M4.5 V. We conclude that the star is a companion to GJ 4100; we therefore rename GJ 4100 as GJ 4100A, and adopt the name GJ 4100B to the low-mass companion.

We find a relative proper motion between GJ4100A and GJ4100B of ≈ 11 mas yr^{-1}, significant only at the 2σ level. At ≈ 45pc, the outer limit of the Gliese & Jahreiss (1991) estimated distance range, the projected separation between the components would be r$\approx$ 600AU, giving an orbital period $\approx 1.5 \times 10^4$ years. At 45pc, the expected orbital motion would be on the order of 5 mas yr^{-1}, which would be consistent with the marginal relative proper motion we measure.

The spectrum of GJ4100 B, when compared to the other M4.5 V star GJ718B (see figure 1), shows what appears to be a weak excess emission at the wavelength of the H_α line. A division between the two spectra does indeed show an excess in H_α at 5σ of the instrumental noise. Hence, GJ4100B is apparently an emission line star, although the H_α emission is very weak and would certainly have been missed on a noisier spectrum. We assign this star a spectral type M4.5 Ve.

EDITOR: PLACE FIGURE 4 HERE.

4.5. *GJ 4153AB*

This is the high proper motion star Wolf 1351, a known flare star. No trigonometric parallax measurement exists for this star, but Gliese & Jahreiss (1991) give an estimated

parallax px=43.0±7.0 mas, based on the color and spectral type. The star is thus estimated to be in the distance range 20pc$\lesssim d \lesssim$ 28pc.

The r = 14.7 proper motion companion 50.5″ to the southeast (Figure 5) was serendipitously discovered by McCarthy, Zuckermann, & Becklin (2001), in a search for close companions to nearby stars. Based on optical and infrared colors, they suggested a spectral type M2.5 V. Our Lick spectrum shows the star to be M3.5 V. We assign the name GJ 4153A to the primary, and GJ 4153B to its distant companion. Both stars have counterparts in the *2MASS Point Source Catalogue, 2MASS 2000 Second Incremental Release*, with infra-red magnitudes K_s=7.36 and 10.60, respectively; McCarthy, Zuckerman, & Becklin (2001) have measured similar values of K=7.39 and 10.60.

EDITOR: PLACE FIGURE 5 HERE.

5. Conclusions

We have confirmed the suspicion of McCarthy, Zuckerman, & Becklin (2001) that a significant number of known nearby stars have unrecognized distant companions that are recorded in the Digitized Sky Survey. We believe that this is largely due to the incompleteness of published proper motion surveys, which is especially bad in the crowded fields of the Milky Way. Our automated search for high proper motion stars at low galactic latitudes ($-25° < b < +25°$) in the region $16h$ <RA< $22h$ DEC> $-2.5°$, has turned up over 2000 new high proper motion stars, of which 4 were found to be unrecognized common proper motion companions of known nearby stars (we also recovered the companion found by McCarthy, Zuckerman, & Becklin 2001).

Our survey area contained only 346 of the stars listed in the *Preliminary Version of the*

Third Catalogue of Nearby Stars (Gliese & Jahreiss 1991), which lists a total of 3803 stars. A simple extrapolation suggests that there exist ≈50 more unrecognized common proper motion companions to GJ stars. However, our survey covers mainly crowded, low galactic latitude fields where we do expect to find a larger number of unidentified (especially faint) proper motion companions. It is likely that fewer common proper motion companions to GJ star remain to be found at higher galactic latitudes. Nevertheless, our survey has so far covered only 25% of the low galactic latitude fields; it is thus reasonable to expect that at least ≈ 15 more unrecognized proper motion companions will be found.

On the other hand, there are known wide binaries with angular separations larger than the 1.5′ limit used in the present study. Out of the 224 multiple systems with separation $\rho > 10''$ listed in Poveda *et al.* (1994), 52 have a separation $\rho > 1.5'$. Given that common proper motion doubles are easier to identify when they are relatively close to each other, we strongly suspect that there are still more unidentified wide binaries with $\rho > 1.5'$. We therefore plan to extend our search for wide binaries to potential proper motion doubles with larger angular separations.

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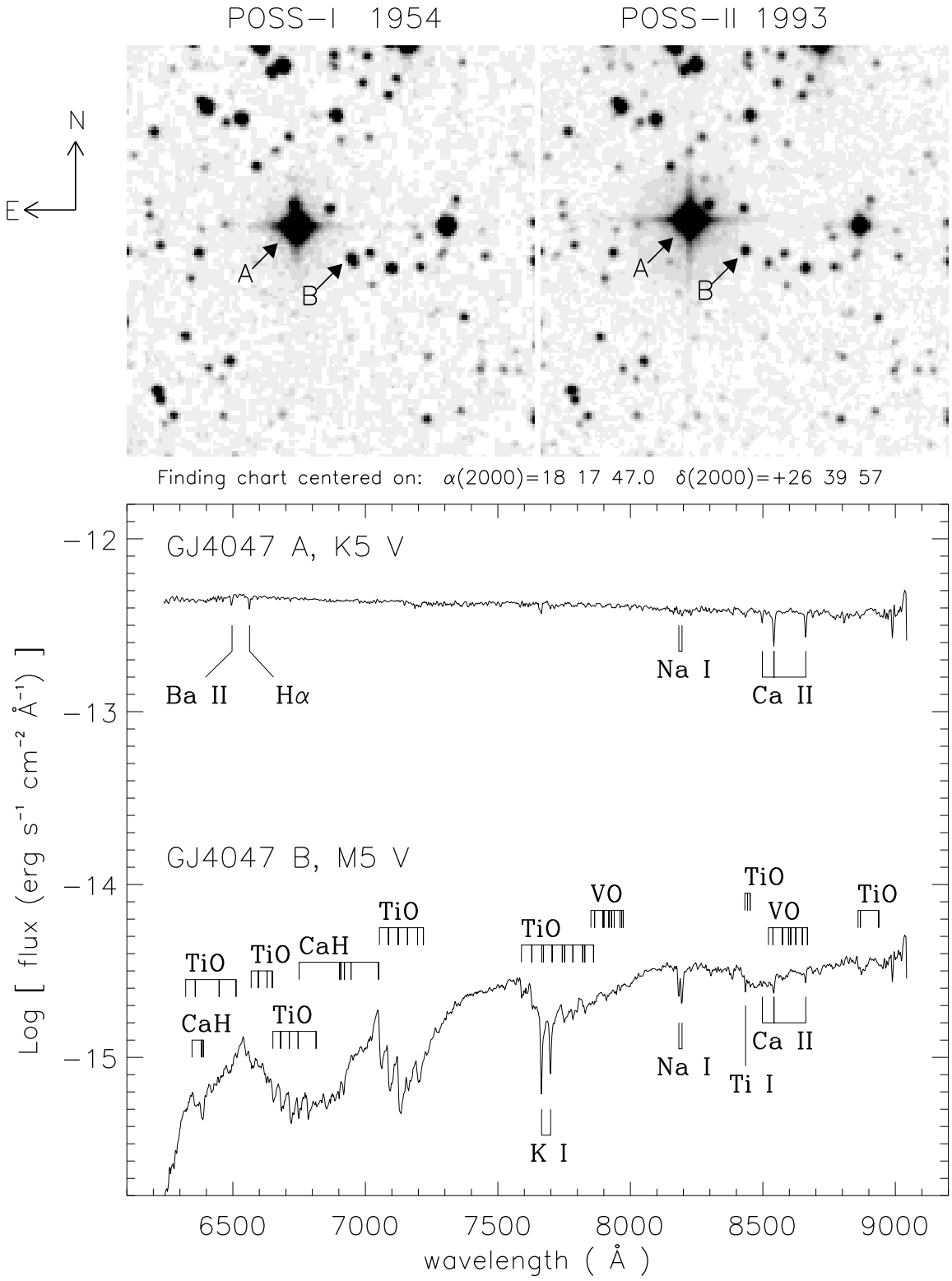

Fig. 1.— Top: finding chart for the star GJ 4047A and its newly discovered distant companion GJ 4047B. Bottom: spectra of the two stars plotted on on the same logarithmic scale.

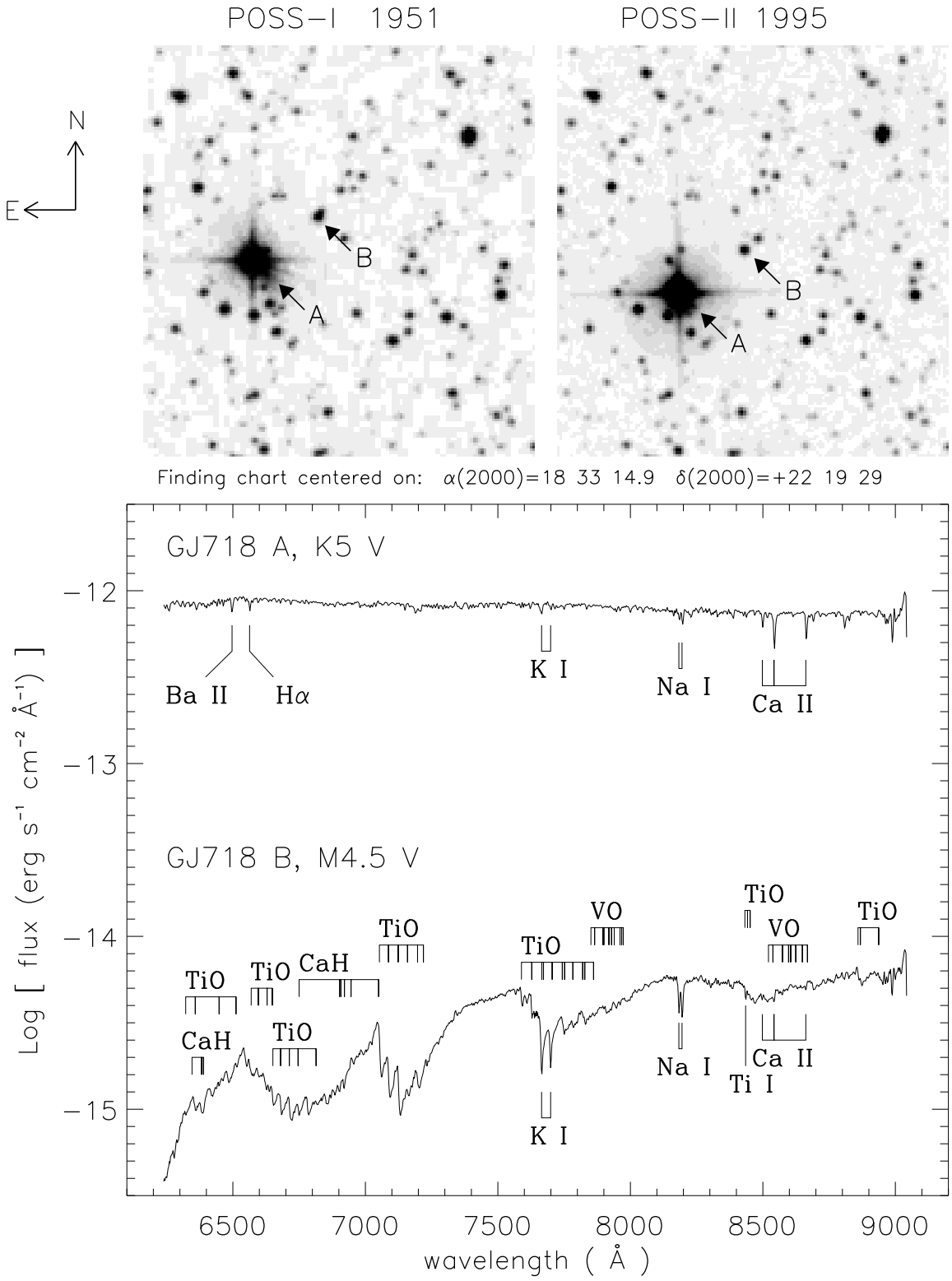

Fig. 2.— Finding chart and spectra for the GJ 718AB system, as is Figure1.

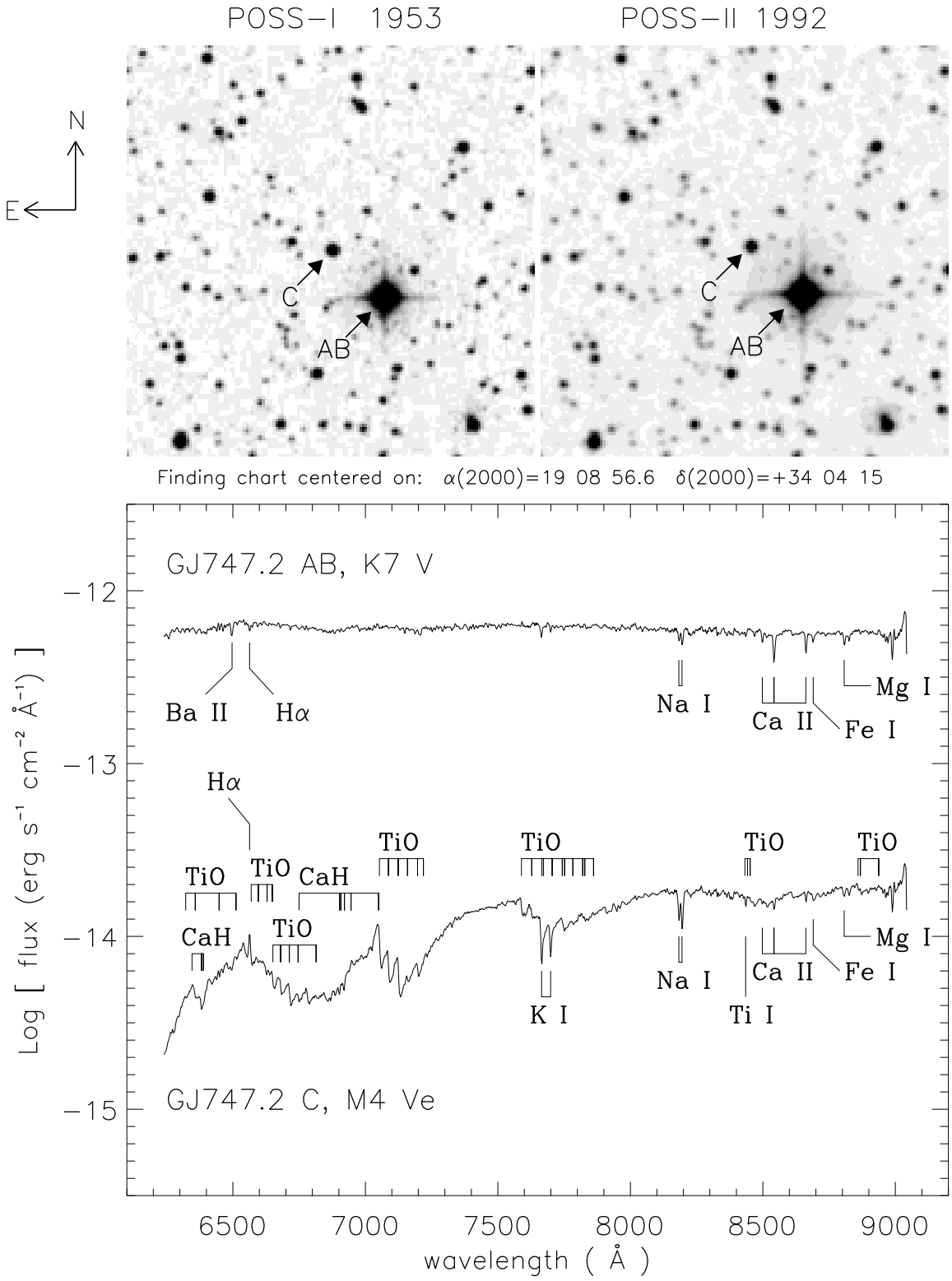

Fig. 3.— Finding chart and spectra for the GJ 747.2ABC system, as is Figure1. Components A and B are only 0.142″ apart, and are not resolved on the charts. A and B and not resolved

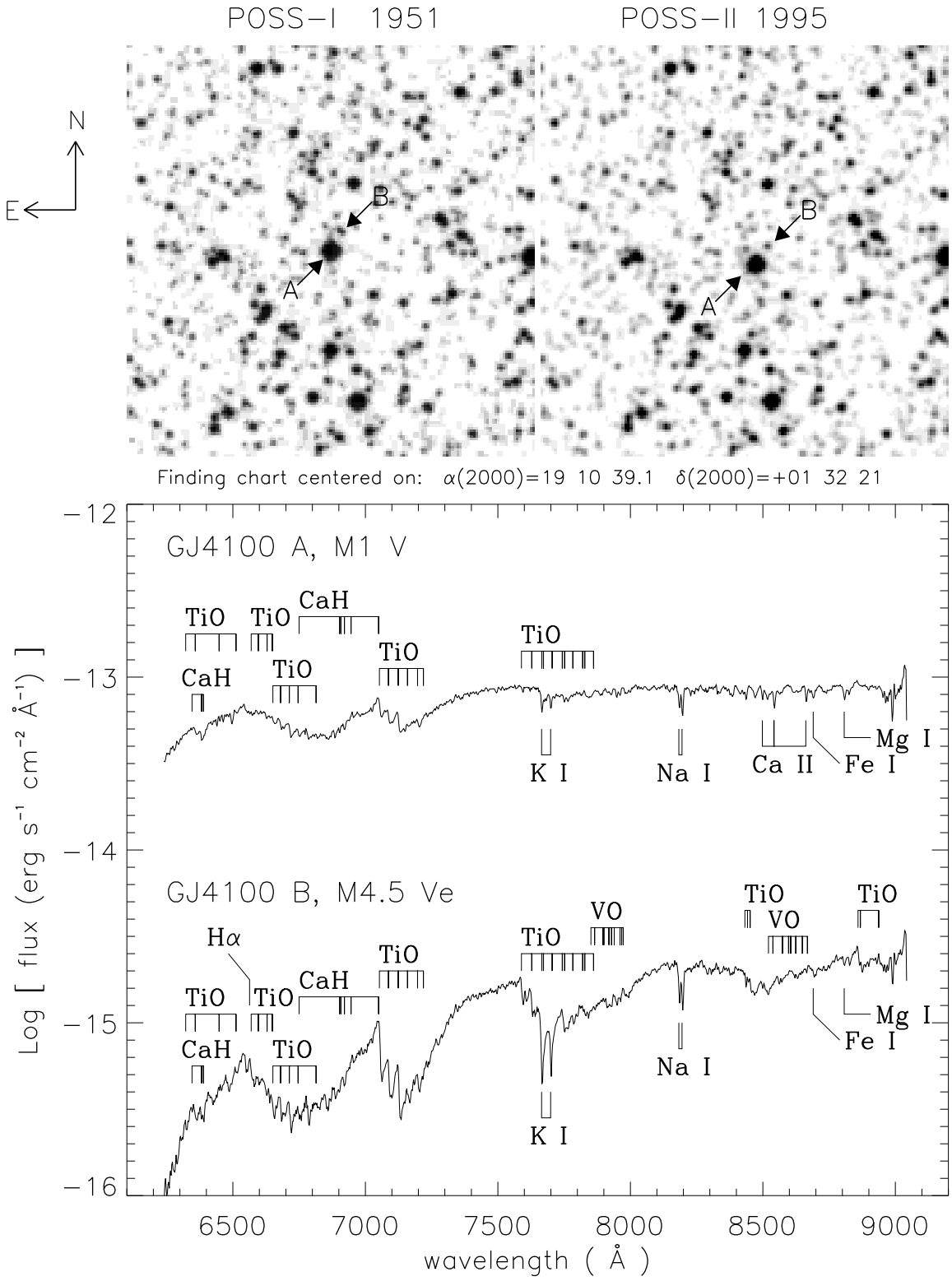

Fig. 4.— Finding chart and spectra for the GJ 4100AB system, as is Figure1.

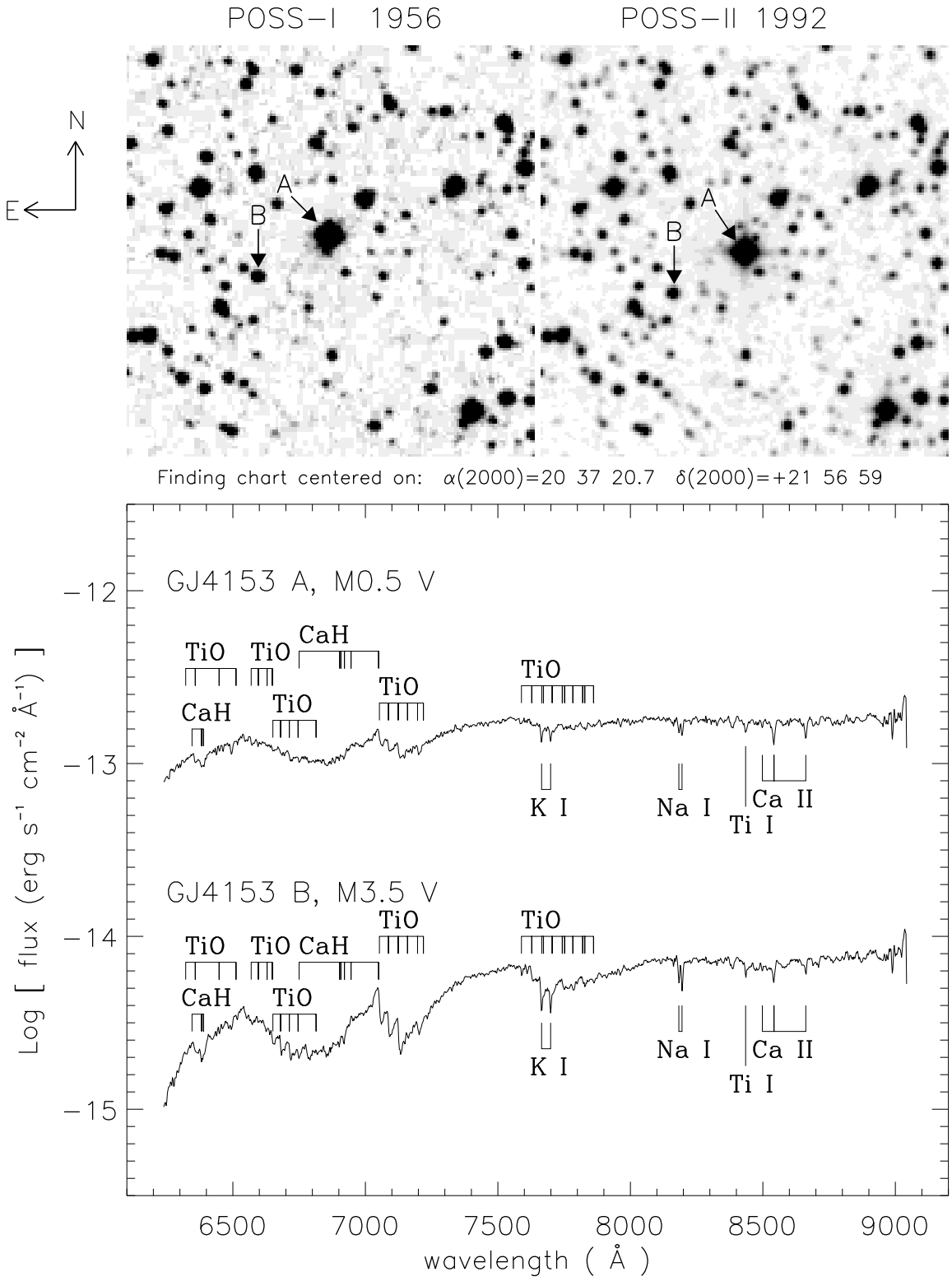

Fig. 5.— Finding chart and spectra for the GJ 4153AB system, as is Figure1.

Table 1. New nearby doubles: coordinates, proper motions, magnitudes

Star	$\alpha(2000.0)$[1]	$\delta(2000.0)$[1]	$\dot{\alpha}$(mas yr^{-1})	$\dot{\delta}$(mas yr^{-1})	b [2]	v [3]	r [4]	K_s [5]
GJ4047A	18 17 49.83	+26 40 17.8	+326	+112	10.9	9.7	···	···
GJ4047B	18 17 47.19	+26 39 57.5	+311	+116	18.3	···	16.0	···
GJ718A	18 33 17.74	+22 18 46.5	-176	-473	10.4	9.0	···	···
GJ718B	18 33 14.76	+22 19 17.3	-172	-472	17.6	···	14.9	···
GJ747.2AB	19 08 53.87	+34 03 44.6	-82	+54	11.2	9.6	···	6.32
GJ747.2C	19 08 56.53	+34 04 14.4	-88	+63	15.9	···	13.6	9.59
GJ4100A	19 10 38.54	+1 32 10.4	-167	-192	···	12.0	···	···
GJ4100B	19 10 38.05	+1 32 21.7	-159	-200	19.0	···	16.6	···
GJ4153A	20 37 20.77	+21 56 48.8	-45	-296	12.7	11.2	···	7.36
GJ4153B	20 37 24.03	+21 56 26.3	-40	-294	17.1	···	14.7	10.60

[1]J2000 equatorial coordinates at epoch 2000.00

[2]POSS-II J blue magnitudes (IIIaJ + GG385)

[3]Pal Q-V visual magnitude (IIaD + W12)

[4]POSS-II F red magnitude (IIIaF + RG610)

[5]2MASS infrared magnitude

Table 2. New nearby doubles: spectroscopic indices, spectral type

Star	CaH1	CaH2	CaH3	TiO5	spectral type
GJ4047A	0.992	0.998	0.987	0.982	K5 V
GJ4047B	0.703	0.306	0.594	0.271	M5 V
GJ718A	0.995	0.995	0.985	0.981	K5 V
GJ718B	0.790	0.357	0.654	0.315	M4.5 V
GJ747.2AB	0.955	0.926	0.953	0.935	K7 V
GJ747.2C	0.735	0.391	0.638	0.407	M4 Ve
GJ4100A	0.835	0.610	0.812	0.657	M1 V
GJ4100B	0.817	0.342	0.657	0.316	M4.5 Ve
GJ4153A	0.846	0.660	0.819	0.700	M0.5 V
GJ4153B	0.783	0.440	0.708	0.446	M3.5 V